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ILLINOIS STATE GEOLOGICAL SURVEY John C. Frye, Chief Urbana, Illinois

November 1966



INDUSTRIAL MINERALS NOTES NO.28

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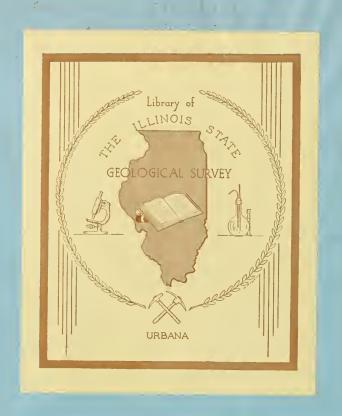
# ILLINOIS CLAYS AS BINDERS FOR IRON ORE PELLETS— A FURTHER STUDY

H. P. Ehrlinger III, M. B. Mirza, L. R. Camp, and H. W. Jackman

#### ABSTRACT

Clays from 13 areas in 10 counties of Illinois, from the northern border to the Ohio River and from the east-central area to the Mississippi River, were tested to determine their value as binding agents for the growing iron ore pelletizing industry.

Some of the Illinois clays treated with soda ash make binders that show excellent possibilities of being commercially acceptable. Iron ore pellets containing these clays develop green strength and fired strength as high as those of pellets made with the universally accepted western bentonites. Dry strength is not as high as when bentonite is used as a binder, but sufficiently high to be acceptable for most applications.



### ILLINOIS CLAYS AS BINDERS FOR IRON ORE PELLETS— A FURTHER STUDY

#### INTRODUCTION

The pelletizing of iron ore in the United States, which started in the 1950's, is growing at an impressive rate. Annual domestic capacity is 33,500,000 tons, facilities with a 15,950,000-ton capacity are under construction, and an additional 3,750,000-ton annual production is indicated at "potential" (planned) pellet plants.\* When plants now in operation are augmented by those under construction, 49,450,000 tons of pellets will be produced annually. As each ton will contain from 13 to 16 pounds of binder, 300,000 to 400,000 tons of binder will be needed each year.

In April 1965, the Illinois State Geological Survey published Industrial Minerals Notes 22, "Illinois Clays as Binders for Iron Cre Pellets," which reported that certain Illinois clays, properly prepared, could be used in making pellets, arousing the interest of Illinois producers of montmorillonite clays and of iron ore producers in nearby states.

This study was made to determine whether additional Illinois clays, located reasonably close to iron mines, had bonding characteristics good enough to make them attractive substitutes for western bentonites.

#### CLAYS TESTED

Twelve samples of accretion-gley (clay deposits formed on the surface of glacial till) from 11 areas in 8 counties, one sample of underclay from a coal area in southwestern Illinois, one sample from Pulaski County which was the most promising clay from the previous report, and one sample of the generally accepted bentonite were tested. The source areas of the samples tested in the reports are shown in figure 1, and table 1 gives the sample locations and general geologic and mineralogic information. The new samples came from Effingham, Montgomery, Sangamon, Adams, Pike, Fulton, Ogle, Stephenson, and St. Clair Counties.

The clay from Pulaski County and the bentonite were retested to serve as a basis of comparison for the other clays. The Pulaski County clay has shown adaptability in plant tests and the bentonite is accepted by the pelletizing industry. Too, there is such a wide difference in reporting the green, dry, and fired strengths of pellets that they provided a better comparison of results than ounces and pounds alone.

<sup>\*</sup>Iron &re-News Highlights of 1965, American Iron Cre Association, Cleveland, Chio.

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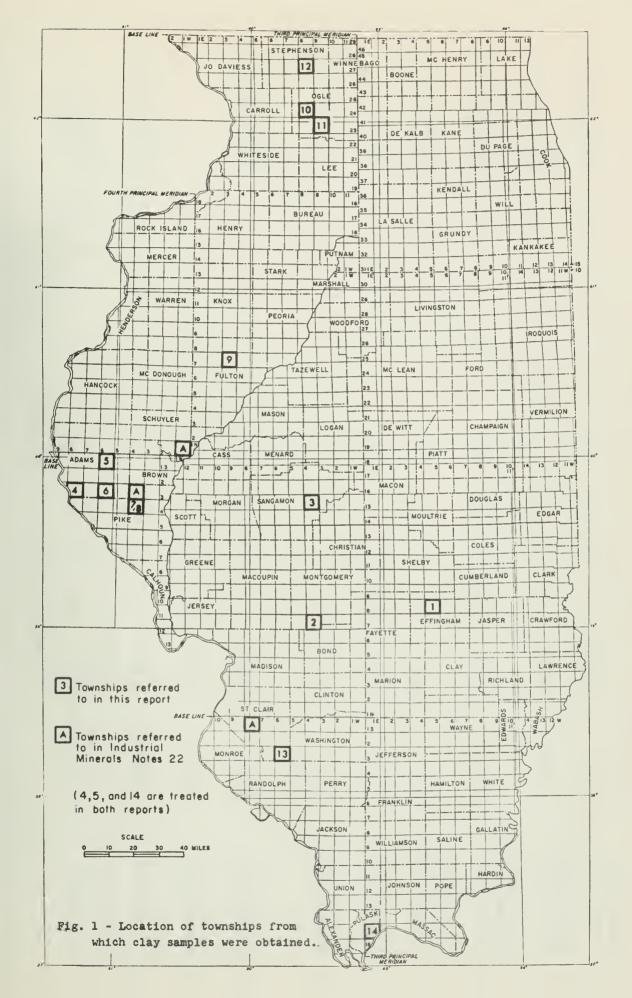
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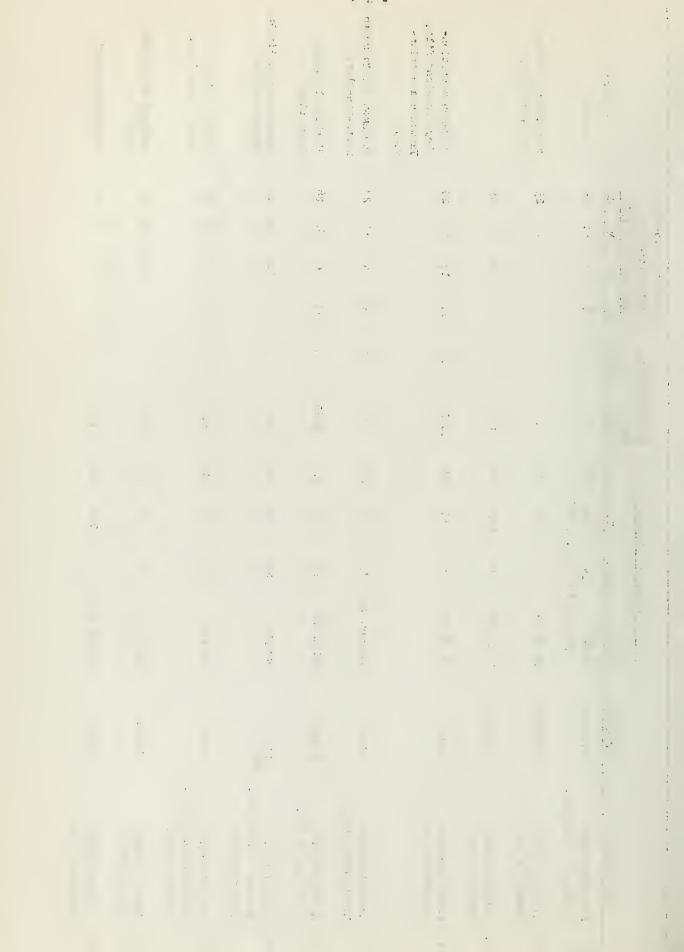
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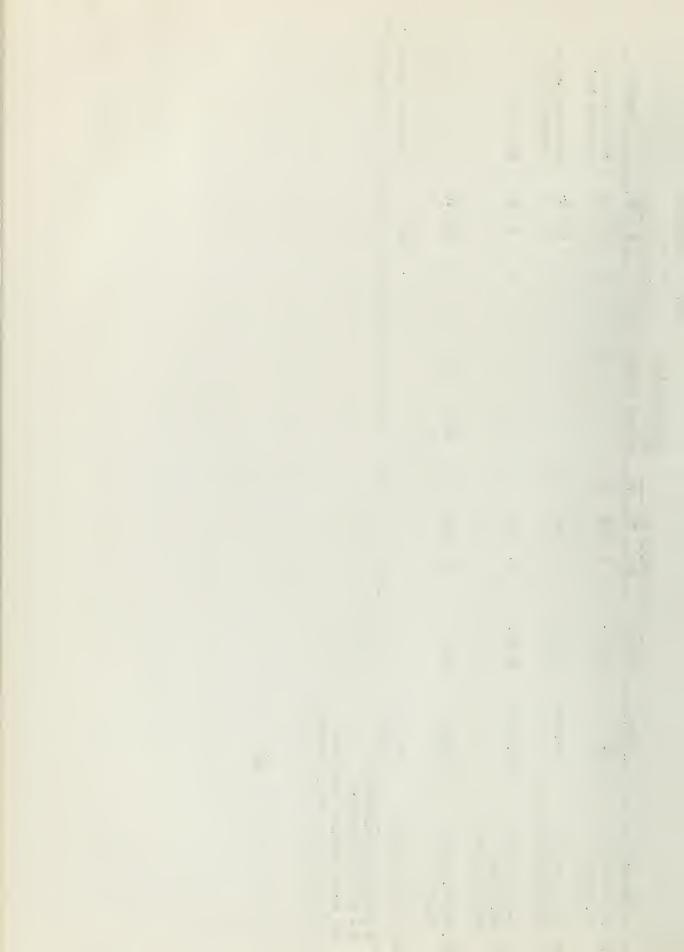
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			O I	Locati	t o n		Thickness (ft.)	(ft.)	inte	intensities of	es of		
							Over-		clay	clay minerals (%)	31s (9	3)	
1	Clay sample	County	Quarter	Sec.	T.	H.	burden	Clay	×	н	Σ	MX	Remarks
r <del>i</del>	Accretion-gley Funkhouser East sec.	Effingham	SE SW 34 8N (North side of U.S. 40)	34 de of	8N U.S. 40)	35	r.	±	7	0	19	32	μ' channel
2	Accretion-gley Panama "A" sec.	Montgomery	SW SW SE	23	7N	M th	N	#	~	9	99	25	Overburden is loess and gleyed loess
ñ	Accretion-gley Rochester sec.	Sangamon	NV SE NW	34	1 5N	Mή	10	5	#	ω	55	31	
	Accretion-gley Zion Church sec.	Adams	SE SE SU	6	38	8 W	10-25	10	11	17	43	29	Sangamon accretion- gley, Loveland Silt, Yarmouth accretion- gley
ů.	Accretion-gley Lierle Creek sec.	Adams	SE cor. SW	33	18	M9	ω	ω	∞	#	61	27	Sangamon and Yarmouth & accretion-gleys
••	Accretion-gley Akers School sec.	Adams	NE NE NE	11	38	м9	8-20	ſΛ	11	0	61	28	5' channel sample Sandy clay
7.	Accretion-gley Woodland School sec. (lower sample)	Pike	SW NE	59	\$ 7	Mή	15	M	9	10	69	17	Unweathered Baylis Fm. (Cretaceous) 3'
ထိ	Accretion-gley Woodland School sec. (upper sample)	P1!te	SW NE	6.	# S	Μħ	11	#	10	0	53	37	Weathered Cret- aceous below loess
9	Accretion-gley Hipple School	Fulton	NW SW SW	ω	ZN	3E	ω	#	7	11	55	27	Sangamon accretion- gley
10.	Accretion-gley Forreston sec.	Ogle	NW SW NE	~	24N	8E	2-10	70	2	0	65	23	On Winnebago Till



								Relat	Relative defraction	fract	ton	
						Thickness (ft.	(rt.)	int	intensities of	es of		
		Loc	cation	u o		Over-		clay	clay minerals (%)	als (	(%)	
Clay sample	County	Quarter	Sec.	E	R.	burden	Clay	X	н	M	MX	Remarks
11. Accretion-gley Mt. Morris sec.	0gle	NE cor.	0	23N	9E	8	#	2	28	52	13	Accretion-gley on Winnebago Till
12. Accretion-gley Cedarville East sec.	Stephenson	NE cor.	#	27N	8E	N	W	2	0	31	29	Accretion-gley on Winnebago Till
13. Underclay below No. 6 Coal River King Mine	St. Clair	SE NE SE	50	% S2	M9	50	2	0/	† <del>†</del>	0	24	Underclay
14. Porters Creek Olmsted	Pulaski	NE SE	27	158	田	20-40	20	~	0	78	10	
15. Western bentonite  K = Kaolinite constituents	State of Wroming							0	0	66	rl	Commercial product

I = Illite constituents

M = Montmorillonite constituents
Mx = Mixed layers, mostly expandable



#### SAMPLE PREPARATION

The raw clay samples were air dried to about 8 percent moisture, crushed in a laboratory jaw crusher set at an opening of a quarter of an inch, and screened on a 3-mesh sieve, with the oversize passed through crushing rolls set at slightly less than 3 mesh. The material was kept in closed circuit until all of it had passed through that screen.

The screened samples were mixed by standard coning and quartering, after which representative 5-kilogram samples were taken for further work. These were dried for 24 hours at  $224^{\circ}$  F ( $107^{\circ}$  C) in a laboratory drier with controlled heat.

One kilogram of each of the clays was taken for size analysis of its individual grains. Each of these samples was subjected to 30 minutes of wet attrition, during which the agglomerates but not the individual grains were broken up. After attrition, the pulp (clay and water) was passed through a 325-mesh (44-micron) screen. Both the sand and slime fractions were dried. The sand was sized on conventional 35- to 325-mesh screens. The minus-325-mesh cake of each of 15 samples was sized in a Roller Particle Size Analyzer. The coarse material had already been removed from the Pulaski County clay and bentonite. Complete as-received size analyses appear in table 2.

TABLE 2 - SIZE ANALYSES OF CLAY SAMPLES AS RECEIVED

Sample		1	2		3		4			5
County	Effir	ngham	Montgo	mery	Sanga	amon	Ada	ms	Ada	ams
Section	Funkhou	user E.	Panama	<sup>11</sup> A <sup>11</sup>	Roche	ester	Zion C	hurch	Lierle	Creek
		Cum1.		Cuml.		Cuml.		Cuml.		Cuml.
	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.
+35 mesh	4.04	4.04	4.64	4.64	2.98	2.98	5.62	5.62	1.28	1.28
+48 mesh	6.93	10.97	6.69	11.33	3.01	5.99	6.60	12.22	3.70	4.98
+65 mesh	4.38	15.35	5.94	17.27	2.99	8.98	5.76	17.98	3.37	8.35
+100 mesh	2.78	18.13	4.09	21.36	3.64	12.62	4.51	22.49	2.78	11.13
+150 mesh	1.70	19.83	2.70	24.06	4.16	16.78	3.31	25.80	2.00	13.13
+200 mesh	1.70	21.53	2.48	26.54	5.85	22.63	3.44	29.24	2.15	15.28
+325 mesh	2.07	23.60	2.93	29.47	5.61	28.24	4.10	33.34	3.03	18.31
+40 micron	3.03	26.63	0.68	30.15	1.48	29.72	2.10	35.44	1.72	20.03
+30 micron	11.70	38.33	9.57	39.72	7.78	37.50	8.90	44.34	8.08	28.11
+20 micron	14.89	53.22	16.46	56.18	13.11	50.61	13.99	58.33	16.66	44.77
+10 micron	22.59	75.81	20.02	76.20	18.67	69.28	17.78	76.11	23.60	68.37
+5 micron	12.92	88.73	14.26	90.46	18.10	87.38	15.10	91.21	20.52	88.89
-5 micron	11.27		9.54		12.62		8.79		11.11	

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TABLE 2 - (Continued)

Sample	6		7		8		9		10	
County	Ada	ms	Pike		Pike		Fulto	n	Og1	е
			Woodland	School	Woodland			-		
Section	Akers S	chool	(lower s		(upper s		Hipple S	chool	Forres	ton
		Cum1.		Cum1.		Cuml.		Cuml.		Cuml
	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt
+35 mesh	3 <b>.3</b> 9	3.39	3.48	3.48	0.87	0.87	5.31	5.31	1.77	1.7
+48 mesh	5.85	9.24	5.08	8.56	1.87	2.74	6.31	11.62	3.20	4.9
+65 mesh	5.35	14.59	6.06	14.62	2.49	5.23	4.59	16.21	2.94	7.9
+100 mesh	4.10	18.69	3.78	18.40	2.13	7.36	3.36	19.57	2.57	10.4
+150 mesh	2.88	21.57	2.21	20.61	1.38	8.74	2.37	21.94	1.90	12.3
+200 mesh	3.17	24.74	3 00	22 (2	3 70	30.37	0.50	Oly July	0.00	21. 7
			1.99	22.60	1.39	10.13	2.50	24.44	2.00	14.3
+325 mesh	3.39	28.13	2.20	24.80	1.65	11.78	3.11	27.55	3.09	17.4
+40 micron	1.69	29.82	0.89	25.69	1.62	13.40	0.53	28.08	0.76	18.2
+30 micron	7.22	37.04	10.63	36.32	8.78	22.18	4.04	32.12	8.19	26.4
+20 micron	15.67	52.71	16.49	52.81	21.85	44.03	11.86	43.98	17.37	43.7
+10 micron	20.65	73.36	24.93	77.74	27.43	71.46	21.92	65.90	24.47	68.2
+5 micron	15.96	89.32	15.27	93.01	22.12	93.58	19.55	85.45	20.33	88.5
-5 micron	10.68		6.99		6.42		14.55		11.41	
Sample	1	1		12		13	14			15
County	0g	le.	Sten	henson	₫+	Clair	Pula	eki		te of ming
, curry			Воср	ile		liver	1 010	JAL	11,701	11.115
Section	Mt. M	lorris	Cedarv	ille East		ng Mine	Olms	ted	Unkı	nown
		Cuml.		Cum1.		Cum1.		Cum1.		Cum
	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% W
+35 mesh	1.91	1.91	1.82	1.82	9.32	9.32				
+48 mesh	4.08	5.99	5.49	7.31	1.39					
+65 mesh	4.25	10.24	4.18	11.49	0.82					
+100 mesh	4.18	14.42	2.89	14.38	0.93	-				
+150 mesh	3.01	17.43	1.74	16.12	0.90					
+200 mesh	2.85	20.28	1.57	17.69	1.39					
+325 mesh	3.11	23.39	1.87	19.56	2.31					
+40 micron	0.53	23.92	0.29	19.85	0.06		6.43	6.43	20.46	
+30 micron	3.75	27.67	2.97	22.82	0.79		8.10	14.53	11.25	31.
+20 micron	9.15	36.82	11.11	33.93	3.72	21.63	11.72	26.25	15.66	47.
+10 micron	18.94	55.76	24.73	58.66	14.66		28.14	54.39	20.69	52.
+5 micron	25.02	80.78	27.44	86.10	34.44		30.25	84.64	22.46 9.48	90 .
-5 micron	10 22		13 00		29.27		15.36			

<sup>-5</sup> micron 19.22 13.90 29.27 15.36 9.48 Clays 14 and 15 were prepared clays and only sub-sieve analyses were made on them.

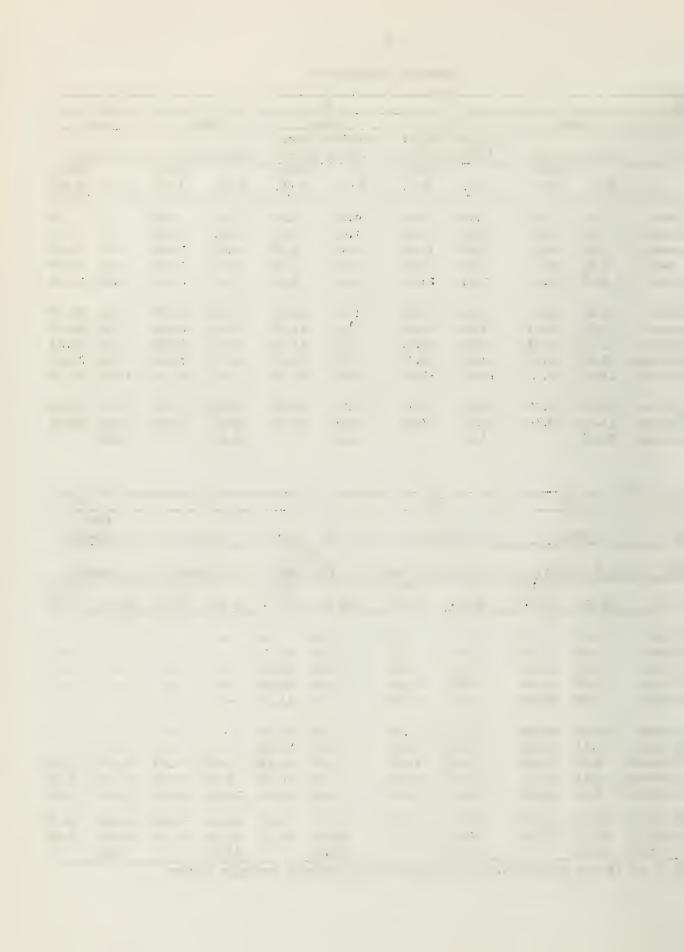


TABLE 3 - SIZE ANALYSES OF CLAYS USED IN PELLETIZING
TEST SERIES A AND B

Samp	ole	11		2	3	4	5	6	7
Cour	nty	Effingham	Mon	tgomery	Sangamon	Adams	Adams	Adams	Pike
		Funkhouser	P	anama		Zion	Lierle	Akers	Woodland
Sec	tion	East		"A"	Rochester	Church	Creek	School	(lower)
Toni	nage factor*	1.309		1.418	1.394	1.500	1.224	1.391	1.330
		% wt.		% wt.	% wt.	% wt.	% wt.	% wt.	% wt.
	+40 micron	<b>3.9</b> 6		0.96	2.06	3.15	2.11	2.35	1.19
-40	+30 micron	15.32		13.57	10.85	13.36	9.89	10.05	14.13
- 30	+20 micron	19.48		23.34	18.26	20.99	20.39	21.81	21.92
-20	+10 micron	29.56		28.39	26.02	26.67	28.89	28.73	33.16
-10	+5 micron	16.91		20.22	25.23	22.66	25.12	22.20	20.30
	-5 micron	14.77		13.52	17.58	13.17	13.60	14.86	9.30
Sam	ole	8	9	10	11	12	13	14	15
							St.		State of
Cour	nty	Pike	Fulton	0gle	Ogle	Stephenson	Clair	Pulaski	Wyoming
		Woodland	Hipple		Mt.	Cedarville	River		
Sect	tion	(upper)	School	Forrestor	Morris	East	King M.	01msted	Unknown
Ton	nage factor*	1.134	1.380	1.212	1.305	1.243	1.206	**	**
		% wt.	% wt.	% wt.	% wt.	% wt	% wt.	% wt.	% wt.
	+40 micron	1.84	0.73	0.92	0.69	0.36	0.07	6.43	20.46
-40	+30 micron	9.95	5 • 57	9.92	4.90	3.69	0.95	8.10	11.25
-30	+20 micron	24.77	16.38	21.04	11.95	13.81	4.49	11.72	15.66
-20	+10 micron	31.09	30.26	29.65	24.72	30.74	17.67	28.14	20.69
-10	+5 micron	25.08	26.98	24.63	32.66	34.11	41.53	30.25	22.46
	-5 micron	7.27	20.08	13.84	25.08	17.29	35.29	15.36	9.48

<sup>\*</sup> Tonnage factor is the number of tons of dry raw clay needed to produce one ton of quality clay.

#### LABORATORY TESTS

Green strength, dry strength, and fired strength were the three main properties considered in the laboratory tests. The green strength is of considerable importance in commercial practice as it is the property that holds the pellet together when it is moved from the balling device to the furnace. The dry strength supports the burden during the transition from wet to fired conditions. This is important in the travelling grate furnaces, and in the shaft furnaces used at some plants it is the most important single criterion in selecting binding agents. The fired strength must be sufficient to keep the pellet together during cooling, stockpiling, loading, and all subsequent handling.

Industrial Minerals Notes 22 showed that the finer the clay, the stronger the pellets that could be made with it. After that report was

Samples 14 and 15 were delivered to the Survey's laboratories as finished products and no tonnage figures are available.

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TABLE 4 - SIZE ANALYSES OF CLAYS USED IN PELLETIZING
TEST SERIES C

Sample	1	2		3	4	5	6	7
County	Effingham	Montgo	omery S	angamon	Adams	Adams	Adams	Pike
	Funkhouser	Pana			Zion	Lierle	Akers	Woodland
Section	East	"A"	r R	ochester	Church	Creek	School	(lower)
Tonnage factor*	2.138	2.2	282	2.025	2.400	1.811	2.115	2.119
	% wt.	% 1	vt.	% wt.	% wt.	% wt.	% wt.	% wt.
-20 +10 micron	48.27	45.	.70	37.80	42.67	42.73	43.67	52.83
-10 +5 micron	27.62	32	• 55	36.65	36.25	37.15	33.75	32.35
+5 micron	24.11	21	.75	25.55	21.08	20.12	22.58	14.82
	0							
Sample	8	9	10	11	12	13	14	15
0	Dales	Tina I do a sa	0.03.	0-7	041	St.	Dud a stat	State of
County	Pike	Fulton	Ogle	Ogle 754	Stephenso		Pulaski	Wyoming
a 11	Woodland	Hipple		Mt.	Cedarvill		#3 ·· · · · · · · · ·	771
Section	(upper)	School	Forreston		East	King M.	Olmsted	Unknown
Tonnage factor*	1.787	1.785	1.779	1.583	1.514	1.276		
	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.
-20 +10 micron	49.00	39.14	43.53	29.98	37.43	18.70	38.16	39.31
-10 +5 micron	39.52	34.90	36.17	39.60	41.53	43.95	41.02	42.68
-5 micron	11.48	25.96	20.30	30.42	21.04	37.35	20.82	18.01

- Tonnage factor in this usage is defined as the number of tons of dry raw clay needed to produce one ton of this quality clay.
- \*\* Samples 14 and 15 were delivered to the Survey's laboratories as finished products and no tonnage figures are available.

published, a small amount of sodium carbonate was found to increase the binder strength markedly. Whether this is a sodium replacement on the calcium mont-morillonite or whether it is the result of the dispersing action of the sodium carbonate has not been determined and is beyond the scope of this paper.

As an average of 16 pounds of clay per ton of iron ore is an accepted standard in the industry, three batches of pellets were made from each clay in the following proportions:

- Series A 16 pounds of minus-325-mesh clay per ton of iron concentrate
- Series B 16 pounds of minus-325 mesh clay and 2 pounds of soda ash (sodium carbonate) per ton of iron concentrate
- Series C 16 pounds of minus-20-micron clay per ton of iron concentrate.

The size analyses of the clays used appear in tables 3 and 4.

The binders and the clay were intimately mixed, put into the pelletizing wheel, and wetted with a quantity of water to make desirable pellets.

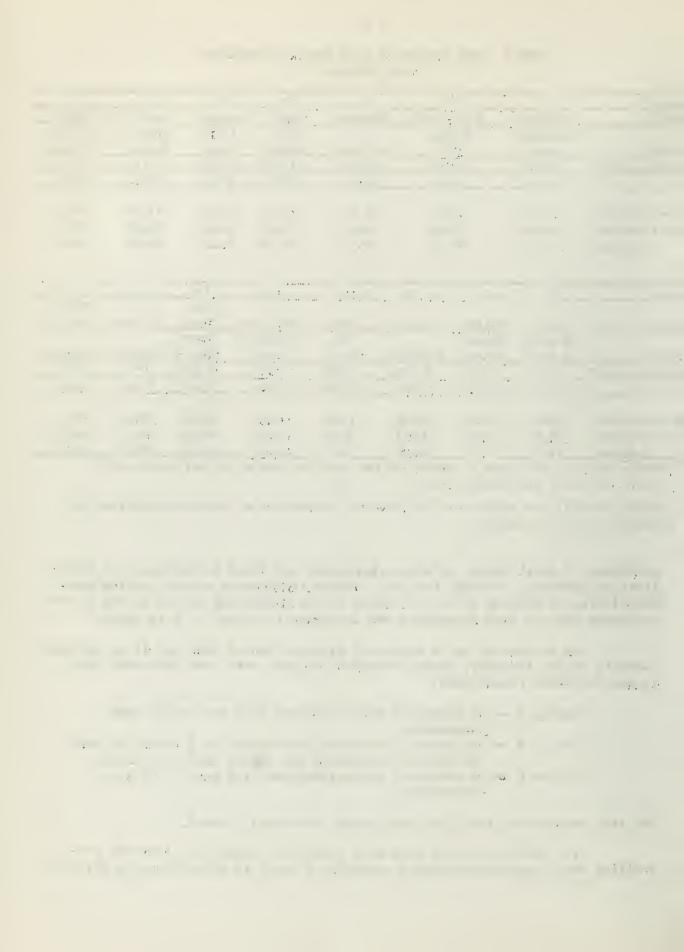


TABLE 5 - TEST RESULTS OF PELLETS MADE WITH IRON ORE CONCENTRATE AND CLAY FOR SERIES A (16 pounds of minus-325-mesh clay per ton of iron ore concentrate)

			Moisture	Drops to	Green	Green strength (oz.)	Dry s	Dry strength (1bs.)	Fired	Fired strength (1bs.
Sample	County	Section	(%)	failure	Av.	Extremes	Av.	Extremes	Av.	Extremes
-	Erfincham	Funkhouser East	8**	2,3	12.8	0.41-0.11	1.9	1.4-2.4	1372	1041-1531
۱ ۵	Montgomerv	Panama "A"	7.0	2.0	13.1	10.5-16.0	1.0	0.7-1.4	1430	1286-1531
, K1	Sangamon	Rochester	5.6	2.0	17.0	11.0-22.0	2.4	1.9-2.9	1496	1348-1531
<b>±</b>	Adams	Zion Church	5.7	2.0	12.3	10.0-14.5	3.0	2.5-3.1	1201	1140-1531
5	Adams	Lierle Creek	h*9	1.9	15.0	10.0-21.0	3.5	2.0-5.1	1404	1072-1531
9	Adams	Akers School	6.5	7.1	12.5	7.0-23.0	2.9	2.0-3.5	1289	735-1531
7	Pike	Woodland (lower)	6.2	2.0	9.5	6.0-15.0	0.8	0.6-1.2	922	368-1225
- ∞	Pike	Woodland (upper)	5.2	2.0	11.7	9.0-15.0	1.8	1.1-2.8	166	674-1531
0	Fulton	Hipple School	6.5	2.0	12.0	10.0-14.0	1.2	0.7-1.5	1162	781-1531
10	ogle	Forreston	ħ• L	1.9	13.3	11.0-18.0	2.0	0.5-0.8	1190	995-1516
=	021e	Mt. Morris	6.3	2.0	13.5	10.0-17.0	6.0	0.5-1.3	1095	750-1501
12	Stephenson	Cedarville East	6.2	2.0	14.6	13.0-17.5	0.8	0.7-1.0	1049	704-1531
13	St. Clair	River King Mine	6.3	2.0	10.8	9.5-14.0	0.5	0.3-0.6	1005	658-1531
17.	Pulaski	Olmsted	7.2	2.0	12.0	10.5-16.0	7.7	0.9-1.3	160	551- 949
15	Wyoming	Unknown	6.5	2.0	13.5	10.5-16.0	9.3	7.1-13.4	898	536-1133
	State									

- 113 1 14 -- -. . : . . . . . . . · - · - 14. (19. kg)

(16 pounds of minus-325-mesh clay and 2 pounds of soda ash per ton of Iron ore concentrate) TABLE 6 - TEST RESULTS OF PELLETS MADE WITH IRON ORE CONCENTRATE AND CLAY FOR SERIES B

			Moisture	Drops to	Green s	Green strength (oz.)	Dry st	Dry strength (1bs.)	Fired a	Fired strength (lbs.
Sample	County	Section	(%)	failure	Av.	Extremes	Av.	Extremes	Av.	Extremes
-	Effingham	Funkhouser East	7.9	2.0	16.3	13.5-20.0	3.0	2.0-4.2	1372	1041-1531
۱ ۸	Montagment	Panama "A"	4.5	2.1	12.5	8.0-17.0	3.6	2.6-4.4	1426	1133-1531
או	Sangamon	Rochester	, 2°, 8°,	2.2	13.8	10.0-20.5	3.9	3.3-5.7	1207	796-1531
۲ ا	Adams	Zion Church	4.9	2.0	10.6	8.5-13.0	4.8	4.0-6.2	1005	582-1363
5	Adams	Lierle Creek	8.3	2.0	16.1	13.0-23.0	5.7	4.2-6.6	1442	1240-1531
V	Adoms	Akens School	5.3	2.0	15.3	12.5-18.0	3.4	2.4-4.2	1083	812=1348
) (	Dilo	Mondland (lower)	6,0	2.0	12.4	10.0-14.5	1.5	1.0-2.0	819	475-1148
- α	Dile	Woodland (upper)	8.7	2.0	12.2	11.0-16.0	1.5	1.1-1.9	730	613- 980
) c	En1 ton	Himle School	6.8	2.0	12.8	10.0-16.0	3.0	2.0-3.7	1072	689-1531
10	Ogle	Forreston	8.9	2.0	16.8	12.5-21.0	3.9	3.3-4.9	1524	1455-1531
	(E)	M+ Monnis	4.9	2.0	13.9	10.0-18.0	2.0	1.3-2.5	986	536-1302
11	Obte	Codomitalo Rost	8.9	2.0	12.9	8.0-16.0	1.2	1.0-1.4	1064	582-1531
77	of Cloth	Bigon King Mine	7 2	0.0	12.0	8.0-18.0	0.9	0.8-1.1	986	613-1322
3 =	Dulochi	Olmeted	٦, ٦	2.0	14.0	12.0-15.5	4.8	4.0-6.0	848	674-1072
15	Wyoming	Unknown	<b>1°</b> L	2.7	16.7	14.5-21.0	4.6	8.4-11.0	1144	766-1531
	State									

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TABLE 7 - TEST RESULTS OF PELLETS MADE WITH IRON ORE CONCENTRATE AND CLAY FOR SERIES C (16 pounds of minus-20-micron clay per ton of iron ore concentrate)

2.0 16.1 13.5-20.0 2.0 15.9 12.0-20.0 2.0 13.9 12.0-20.0 2.0 13.9 11.5-17.0 2.0 10.1 8.0-13.0 1.7 9.9 7.0-13.0 2.0 12.5 10.0-15.0 2.0 14.3 11.0-17.0 1.9 13.8 10.0-18.0 2.0 12.3 10.5-17.0 2.0 12.3 10.5-17.0 2.1 11.3 8.0-15.0 2.1 11.8 8.5-15.0				Moisture	Drops to	Green s	Green strength (oz.)	Dry s	Dry strength (1bs.)	Fired	Fired strength (1bs.)
Effingham         Punkhouser East         6.7         2.0         16.1         13.5-20.0         2.4         1.8-3.0         1473           Nontgomery         Panama "A"         6.3         2.0         15.9         12.0-20.0         2.4         2.1-2.6         1479           Sangamon         Rochester         5.8         2.0         13.7         11.0-16.5         1.3         0.8-1.9         1343           Adams         Liderte Creek         5.8         2.0         10.1         8.0-13.0         2.1         12.2           Adams         Liderte Creek         5.8         2.0         10.1         8.0-13.0         2.1         12.2           Adams         Akers School         5.3         1.7         9.9         7.0-13.0         2.1         13.2           Pike         Woodland (upper)         7.2         1.8         10.8         7.0-15.0         2.4         1.3-2.9         1044           Pike         Woodland (upper)         7.1         2.0         14.5         11.0-15.0         2.4         1.3-2.9         1044           Pilte         Woodland (upper)         7.1         2.0         14.5         11.0-15.0         2.4         1.3-3.5         1044           Og	Sample	County	Section	(%)	failure	Av.	Extremes	Av.	Extremes	Av.	Extremes
Effingham Funkhouser East 6.7 2.0 16.1 13.5-20.0 2.4 1.8-3.0 1433  Wontgomery Panama "A" 6.3 2.0 15.9 12.0-20.0 2.4 2.1-2.6 1479  Sangamon Rochester 5.8 2.0 13.3 11.0-16.5 1.3 0.8-1.9 1447  Adams Zion Church 6.5 2.0 13.9 11.5-17.0 3.2 2.4-4.4 12213  Adams Iders School 5.3 1.7 9.9 7.0-13.0 2.7 2.5-3.0 1044  Parke Woodland (Lower) 7.2 1.8 10.8 7.0-15.0 2.2 2.1-2.4 905  Palke Woodland (Lower) 7.1 2.0 12.5 10.0-15.0 2.2 2.1-2.4 905  Palke Woodland (Lower) 6.3 1.9 14.7 11.0-17.0 1.0 0.7-1.6 1041  Ogle Mt. Morris 6.1 1.9 13.8 10.0-18.0 1.0 0.7-1.6 1041  Stephenson Gedarville East 6.2 2.0 13.9 11.0-17.5 0.7 0.6-0.8 1040  Stephensk Unknown 7.0 2.4 11.8 8.5-15.0 8.0 6.4-9.7 681  State											
Wontgomery         Panama "A"         6.3         2.0         15.9         12.0-20.0         2.4         2.1-2.6         1479           Sangamon         Rochester         5.8         2.0         13.3         11.0-16.5         1.3         0.8-1.9         1343           Adams         Zion Church         6.5         2.0         13.9         11.5-17.0         3.2         2.4-4.4         1213           Adams         Iderle Creek         5.8         2.0         10.1         8.0-13.0         2.1         1.3-2.9         1343           Adams         Akers School         5.3         1.7         9.9         7.0-13.0         2.7         2.5-3.0         1044           Pike         Woodland (upper)         7.2         1.8         10.8         7.0-15.0         2.2         2.1-2.4         905           Pike         Woodland (upper)         7.1         2.0         12.5         10.0-15.0         2.2         2.1-2.4         905           Pike         Woodland (upper)         7.1         2.0         12.5         11.0-15.0         2.2         2.1-2.4         905           Palke         Woodland (upper)         7.1         2.0         12.5         11.0-15.0         2.2         2.	-	E.f.f.1noham	Funkhouser East	6.7	2.0	16.1	13.5-20.0	2.4	1.8-3.0	1433	1225-1531
Sangamon         Rochester         5.8         2.0         13.5         11.0-16.5         1.3         0.8-1.9         1343           Adams         Zion Church         6.5         2.0         13.9         11.5-17.0         3.2         2.4-4.4         1213           Adams         Literle Creek         5.8         2.0         10.1         8.0-13.0         2.1         1.3-2.9         1343           Adams         Akers School         5.3         1.7         9.9         7.0-13.0         2.7         2.4-4.4         1213           Pike         Woodland (lower)         7.2         1.8         10.8         7.0-15.0         2.2         2.1-2.4         905           Pike         Woodland (upper)         7.1         2.0         12.5         10.0-15.0         2.2         2.1-2.4         905           Pike         Woodland (upper)         7.1         2.0         12.5         10.0-15.0         2.2         2.1-2.4         905           Pike         Woodland (upper)         7.1         2.0         12.5         11.0-17.0         2.2         2.1-2.4         905           Pull         Mit         Antion         Antion         Antion         Antion         Antion         Antion </td <td>1 0</td> <td>Montcomerv</td> <td>Panama "A"</td> <td>6.3</td> <td>2.0</td> <td>15.9</td> <td>12.0-20.0</td> <td>2.4</td> <td>2.1-2.6</td> <td>1479</td> <td>1225-1531</td>	1 0	Montcomerv	Panama "A"	6.3	2.0	15.9	12.0-20.0	2.4	2.1-2.6	1479	1225-1531
Adams         Zion Church         6.5         2.0         13.9         11.5-17.0         3.2         2.4-4.4         1213           Adams         Lierle Creek         5.8         2.0         10.1         8.0-13.0         2.1         1.3-2.9         1231           Adams         Akers School         5.3         1.7         9.9         7.0-13.0         2.7         2.5-3.0         1044           Pike         Woodland (Lower)         7.2         1.8         10.8         7.0-15.0         2.2         2.1-2.4         905           Pike         Woodland (Lower)         7.1         2.0         12.5         10.0-15.0         2.4         1.8-3.5         1012           Pike         Woodland (upper)         7.1         2.0         12.5         10.0-15.0         2.4         1.8-3.5         1012           Pulke         Woodland (upper)         7.1         2.0         14.7         11.0-17.0         2.4         1.8-3.5         1012           Pulke         Woodland (upper)         7.1         2.0         14.7         11.0-15.0         2.4         1.8-3.5         1041           Ogle         Wt. Morris         6.3         1.9         14.7         11.0-18.5         3.6         24	1 14	Sangamon	Rochester	5.8	2.0	13.3	11.0-16.5	1.3	0.8-1.9	1343	980-1531
Adams         Literle Creek         5.8         2.0         10.1         8.0-13.0         2.1         1.3-2.9         1231           Adams         Akers School         5.3         1.7         9.9         7.0-13.0         2.7         2.5-3.0         1044           Pike         Woodland (lower)         7.2         1.8         10.8         7.0-15.0         2.2         2.1-2.4         905           Pike         Woodland (lower)         7.1         2.0         12.5         10.0-15.0         2.2         2.1-2.4         905           Fulton         Hipple School         6.4         2.0         14.3         11.0-17.0         2.4         1.8-3.5         1012           Gole         Follower         6.3         1.9         14.7         11.0-17.0         2.4         1.8-3.5         1041           Ogle         Mt. Morris         6.1         1.9         14.7         11.0-18.5         3.6         2.4-4.4         1311           Ogle         Mt. Morris         6.1         1.9         14.7         11.0-18.5         3.6         2.4-4.4         1311           St. Clair         River King Mine         6.0         2.0         12.3         10.5-17.0         0.8         0.5-1.2 <td>トコ</td> <td>Adams</td> <td>Zion Church</td> <td>6.5</td> <td>2.0</td> <td>13.9</td> <td>11.5-17.0</td> <td>3.2</td> <td>7.4-4.5</td> <td>1213</td> <td>781-1531</td>	トコ	Adams	Zion Church	6.5	2.0	13.9	11.5-17.0	3.2	7.4-4.5	1213	781-1531
Adams Akers School 5.3 1.7 9.9 7.0-13.0 2.7 2.5-3.0 1044  Pike Woodland (lower) 7.2 1.8 10.8 7.0-15.0 2.2 2.1-2.4 905  Pike Woodland (upper) 7.1 2.0 12.5 10.0-15.0 2.4 1.8-3.5 1012  Fulton Hipple School 6.4 2.0 14.3 11.0-17.0 1.0 0.7-1.6 1041  Ogle Forreston 6.3 1.9 14.7 11.0-18.5 3.6 2.4-4.4 1311  Ogle Stephenson Cedarville East 6.2 2.0 13.9 11.0-17.5 0.7 0.6-0.8 1040  St. Clair River King Mine 6.0 2.0 12.3 10.5-17.0 0.8 0.5-1.2 784  Pulaski Unknown 7.0 2.4 11.8 8.5-15.0 8.0 6.4-9.7 681  State	. 5	Adams	Lierle Creek	5.8	2.0	10.1	8.0-13.0	2.1	1.3-2.9	1231	1057-1439
Adams Akers School 2.2 1.7 1.8 10.8 7.0-15.0 2.2 2.1-2.4 905  Pike Woodland (lower) 7.2 1.8 10.8 7.0-15.0 2.2 2.1-2.4 905  Pike Woodland (upper) 7.1 2.0 12.5 10.0-15.0 2.4 1.8-3.5 1012  Fulton Hipple School 6.4 2.0 14.7 11.0-17.0 1.0 0.7-1.6 1041  Ogle Mt. Morris 6.1 1.9 13.8 10.0-18.5 3.6 2.4-4.4 1311  Ogle Mt. Morris 6.1 1.9 13.8 10.0-18.0 0.8-1.1 1276  Stephenson Cedarville East 6.2 2.0 13.9 11.0-17.5 0.7 0.6-0.8 1040  St. Clair River King Mine 6.0 2.0 12.3 10.5-17.0 0.8 0.5-1.2 784  Pulaski Olmsted 6.5 2.1 11.8 8.5-15.0 8.0 6.4-9.7 681  State	,			r.		c	7 0-13 0	6	0,5=2,0	1017	735-1531
Pike         Woodland (lower)         7.2         1.8         10.6         (.0-15.0)         2.6         2.1-2.7         30.9           Pike         Woodland (upper)         7.1         2.0         12.5         10.0-15.0         2.4         1.8-3.5         1012           Fulton         Hipple School         6.4         2.0         14.7         11.0-17.0         1.0         0.7-1.6         1041           Ogle         Mt. Morris         6.3         1.9         14.7         11.0-18.5         3.6         2.4-4.4         1311           Ogle         Mt. Morris         6.1         1.9         13.8         10.0-18.5         3.6         2.4-4.4         1311           Stephenson         Cedarville East         6.2         2.0         13.9         11.0-17.5         0.7         0.6-0.8         1040           St. Clair         River King Mine         6.0         2.0         12.3         10.5-17.0         0.8         0.5-1.2         784           Wyoming         Unknown         7.0         2.4         11.8         8.5-15.0         8.0         6.4-9.7         681           State         6.2         2.4         11.8         8.5-15.0         8.0         6.4-9.7         681 </td <td>9</td> <td>Adams</td> <td>Akers School</td> <td>2.5</td> <td>7.7</td> <td>200</td> <td>0.01-0.7</td> <td>. c</td> <td>- 0 - 0</td> <td>300</td> <td>787-174B</td>	9	Adams	Akers School	2.5	7.7	200	0.01-0.7	. c	- 0 - 0	300	787-174B
Pitke         Woodland (upper)         7.1         2.0         12.5         10.0-15.0         2.4         1.8-3.5         1012           Fulton         Hipple School         6.4         2.0         14.3         11.0-17.0         1.0         0.7-1.6         1041           Ogle         Forreston         6.3         1.9         14.7         11.0-18.5         3.6         2.4-4.4         1311           Ogle         Mt. Morris         6.1         1.9         13.8         10.0-18.5         3.6         2.4-4.4         1311           Stephenson         Cedarville East         6.2         2.0         13.9         11.0-17.5         0.7         0.6-0.8         1040           St. Clair         River King Mine         6.0         2.0         12.3         10.5-17.0         0.8         0.5-1.2         784           Pulaski         Olmsted         6.5         2.1         11.3         8.0-15.0         1.9         6.4-9.7         681           State         State         8.5-15.0         8.0         6.4-9.7         681         681	7	Pike	Woodland (lower)	7.2	1.8	10.8	7.0-15.0	7.7	4.2-I.2	302	0101-000
Fulton Hipple School 6.4 2.0 14.3 11.0-17.0 1.0 0.7-1.6 1041 0gle Forreston 6.3 1.9 14.7 11.0-18.5 3.6 2.4-4.4 1311 1276	- 00	P1ke	Woodland (upper)	7.1	2.0	12.5	10.0-15.0	2.4	1.8-3.5	1012	643-1501
Ogle         Mt. Morris         6.1         1.9         14.7         11.0-18.5         3.6         2.4-4.4         1311           Ogle         Mt. Morris         6.1         1.9         13.8         10.0-18.0         1.0         0.8-1.1         1276           Stephenson         Cedarville East         6.2         2.0         13.9         11.0-17.5         0.7         0.6-0.8         1040           St. Clair         River King Mine         6.0         2.0         12.3         10.5-17.0         0.8         0.5-1.2         784           Pulaski         Olmsted         6.5         2.1         11.3         8.0-15.0         1.9         1.1-2.2         905           Wyoming         Unknown         7.0         2.4         11.8         8.5-15.0         8.0         6.4-9.7         681	) 0	Fulton	Hinnle School	ħ*9	2.0	14.3	11.0-17.0	1.0	0.7-1.6	1041	643-1302
Ogle       Mt. Morris       6.1       1.9       13.8       10.0-18.0       1.0       0.8-1.1       1276         Stephenson       Cedarville East       6.2       2.0       13.9       11.0-17.5       0.7       0.6-0.8       1040         St. Clair       River King Mine       6.0       2.0       12.3       10.5-17.0       0.8       0.5-1.2       784         Pulaski       Olmsted       6.5       2.1       11.3       8.0-15.0       1.9       1.1-2.2       905         Wyoming       Unknown       7.0       2.4       11.8       8.5-15.0       8.0       6.4-9.7       681         State       3tate	10	ogle	Forreston	6.3	1.9	14.7	11.0-18.5	3.6	4.4-4.5	1311	919-1531
Ogle         Mt. Morris         6.1         1.9         13.8         10.0-18.0         1.0         0.8-1.1         1276           Stephenson         Cedarville East         6.2         2.0         13.9         11.0-17.5         0.7         0.6-0.8         1040           St. Clair         River King Mine         6.0         2.0         12.3         10.5-17.0         0.8         0.5-1.2         784           Pulaski         Olmsted         6.5         2.1         11.3         8.0-15.0         1.9         11-2.2         905           Wyoming         Unknown         7.0         2.4         11.8         8.5-15.0         8.0         6.4-9.7         681           State										,	
Stephenson         Cedarville East         6.2         2.0         13.9         11.0-17.5         0.7         0.6-0.8         1040           St. Clair         River King Mine         6.0         2.0         12.3         10.5-17.0         0.8         0.5-1.2         784           Pulaski         Olmsted         6.5         2.1         11.3         8.0-15.0         1.9         1.1-2.2         905           Wyoming         Unknown         7.0         2.4         11.8         8.5-15.0         8.0         6.4-9.7         681           State	ונ	000	Mt. Morris	6.1	1.9	13.8	10.0-18.0	1.0	0.8-1.1	1276	613-1531
St. Clair River King Mine 6.0 2.0 12.3 10.5-17.0 0.8 0.5-1.2 784  St. Clair River King Mine 6.5 2.1 11.3 8.0-15.0 1.9 1.1-2.2 905  Wyoming Unknown 7.0 2.4 11.8 8.5-15.0 8.0 6.4-9.7 681  State	5.	Stanhanson	Cedarville East	6.2	2.0	13.9	11.0-17.5	2.0	0.6-0.8	1040	750-1531
Fulaski Olmsted 6.5 2.1 11.3 8.0-15.0 1.9 1.1-2.2 905 Wyoming Unknown 7.0 2.4 11.8 8.5-15.0 8.0 6.4-9.7 681 State	77	מליכוט ביים	Diger King Mine	6.0	2.0	12.3	10.5-17.0	0.8	0.5-1.2	78 <sup>t</sup>	582-1118
Fulaski Olimbred 7.0 2.4 11.8 8.5-15.0 8.0 6.4-9.7 681 State	<b>4</b> 7	Dul- order	Oluctod Mans Mans	, v		77.3	8.0-15.0	1.9	1.1-2.2	905	628-1225
ng Unknown 7.0 2.4 11.6 6.5-15.0 0.0 0.4-5.1	74	rulaski	OTWEEG		4 .	1 1		i a	7 0 1 7	(8)	475- 980
State	15	Wyoming	Unknown	0.7	2.4	11.8	8.5-15.0	0.0	0.4-7.0	100	200
		State									

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The amount of water varied because the individual clays had different absorbencies. After the pellets were formed they were left in the wheel for about 2 minutes so that they would be compacted into spherical units. This time factor approximates that used in pelletizing plants. The pellets were removed from the wheel and screened; subsequent tests for strength were conducted on the minus three-eighths inch and plus one-fourth inch fraction only to make comparisons meaningful.

Ten pellets from each clay sample were subjected to the drop test, in which the pellets are repeatedly dropped 18 inches onto a steel platform until they fail. The number of drops is indicative of strength. Unfortunately, this laboratory test was quite inconclusive as almost all of the pellets failed at the same point. Ten more pellets from each clay sample were tested for green strength. This involves applying a force at a uniform rate to each pellet before it is dried. The force required to crush the pellets was recorded for each and the strength for each series averaged.

The remaining pellets were weighed, dried at  $392^{\circ}$  F ( $200^{\circ}$  C) for 30 minutes, and weighed again. Moisture content of the pellets was determined as follows:

wet weight - dry weight
 wet weight x 100 = % moisture.

Ten dry pellets from each clay sample were tested for dry strength by a procedure similar to that used for the green strength tests. The remaining dry pellets were fired at  $2400^{\circ}$  F  $(1315^{\circ}$  C) for one hour, permitted to cool slowly to  $1450^{\circ}$  F  $(790^{\circ}$  C), and cooling was finished at room temperature. Ten of the fired pellets from each sample were tested on a modified dynamic load tester, which involved pressure to failure. Tables 5, 6, and 7 show the results of these tests.

#### FREE SILICA TESTS

The quantity of cristobalite contained in clays is of universal concern. Cristobalite is a form of silica that is particularly hazardous as a cause of silicosis. While the Illinois clays, with one exception, have high silica contents, X-ray analysis showed no cristobalite in any of them. Table 8 shows the free silica content of the clays tested.

#### CONCLUSIONS

At least seven of the Illinois clays tested display strength that might make them good substitutes for western bentonites as binders for iron ore pellets.

The addition of small quantities of soda ash is required for satisfactory dry strength in pellets made with Illinois clays. Soda ash makes little difference in the development of the green or fired strength.

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TABLE 8 - FREE SILICA DETERMINATION IN MINUS-20-MICRON FRACTION OF CLAY

			% Free
Sample	County	Section	silica
	D.O	<b>.</b>	
1	Effingham	Funkhouser East	43.03
2	Montgomery	Panama "A"	29.38
3	Sangamon	Rochester	36.63
4	Adams	Zion Church	31.69
5	Adams	Lierle Creek	31.05
6	Adams	Akers School	35.90
7	Pike	Woodland (lower)	51.97
8	Pike	Woodland (upper)	41.99
9	Fulton	Hipple School	31.00
10	Ogle	Forreston	43.36
11	Ogle	Mt. Morris	35.76
12	Stephenson	Cedarville East	39.89
13	St. Clair	River King Mine	23.09
14	Pulaski	Olmsted .	0.56
15	Wyoming State	Unknown	1.10

The fired strength of most of the pellets made with Illinois clay was higher than that made with western bentonite. Any fired strength higher than 500 pounds is satisfactory for handling and shipping.

No cristobalite was found in the Illinois clays during X-ray analysis.

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